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BUREAU OF MINES
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INFORMATION CIRCULAR

INSPECTION AND TESTING OF MINE-TYPE ELECTRICAL EQUIPMENT FOR PERMISSIBILITY

BY

L. C. ILSLEY, E. J. GLEIM, AND H. B. BRUNOT

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UNITED STATES DEPARTMENT OF THE INTERIOR - BUREAU OF MINES

INSPECTION AND TESTING OF MINE-TYPE ELECTRICAL EQUIPMENT FOR PERMISSIBILITY[1]

By L. C. Ilsley[2], E. J. Gleim,[2] and H. B. Brunot[3]

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INTRODUCTION

The theory and practice followed by the Bureau of Mines in the investigation of electrical equipment[4] made for service in gassy mines are of particular interest not only to manufacturers but also to those organizations that deal with safety and inspection at the mines.

This publication proposes to discuss the theory upon which tests of equipment in explosive atmospheres are based and to consider inspection and other matters pertaining to investigations made by the Bureau in ascertaining whether a machine merits approval.

The material herein contained is taken from Bulletin 305,[5] which is now out of print, and has been revised and brought up to date to make the information again available to manufacturers, inspectors, and others interested in the development of safe equipment.

ACKNOWLEDGMENT

The authors gratefully acknowledge the work of H. F. Coward, principal assistant, Safety in Mines Research Board, Great Britain, who personally assisted in revising the portions of the text dealing with ignition temperatures and limits of inflammability of methane-air mixtures.

SAFEGUARDING MINE-TYPE ELECTRICAL EQUIPMENT

In the coal-mining industry the recurrence of disastrous mine explosions long ago drew attention to the imperative need for proper safeguards in the use of electricity if such catastrophes were to be prevented. The present-day methods of mining, which involve concentration of a number of electrically driven machines at the working face, make it more than ever necessary that suitable precautions be taken to guard against electric sparks or flashes in explosive atmospheres. The importance of adequate safeguards is realized when it is understood that a current of less than 1 ampere at the brushes of a small 250-volt motor is sufficient to ignite an explosive

4/ Safety lamps, gas detectors, shot-firing units, and other devices not having motors are not included in the meaning of mine equipment as used here.

5/ L. C. Ilsley, E. J. Gleim, H. B. Brunot, Inspection and Testing of Mine-type Electrical Equipment for Permissibility: Bureau of Mines Bull. 305, 1929, 26 pp.

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mixture of mine gas and air and that this is only one of the numerous ways in which sparks can be produced.

The effectual safeguarding of electrical equipment depends on application of two of the practices followed in safeguarding mines against general hazards. The more important and more widely adopted of these is ventilation. Ventilation of gassy mines that is sufficiently effective to force enough fresh air into the mine to dilute and sweep out the gas being liberated and prevent its accumulation in explosive proportions is a tremendous factor in preventing explosions of electrical origin. Ventilation may therefore be considered the first line of defense in preventing ignitions of gas by electricity. Another important safeguard is rock dusting, which may be considered the second line of defense. Following these two in importance should come the use of permissible electrical equipment. The first two safeguards, if adequately planned and maintained, will prevent catastrophes; the third will tend to prevent less widespread explosions at the face. If the first two preventatives are neglected, the last or third may prevent disaster; therefore it is very important to have all electrical equipment in gassy sections of the mine properly safeguarded. "Permissible" equipment should never be used in places where gas exists in amounts sufficient to be detected by a flame safety lamp. Such a procedure is unsafe and can not be too strongly condemned.

CONDITIONS CONDUCIVE TO MINE EXPLOSIONS CAUSED BY ELECTRICITY

The basic conditions that bring about a mine explosion initiated by electrical equipment improperly constructed or maintained are as follows: (1) The presence of gas in the immediate vicinity of the equipment, (2) the penetration of the gas into the equipment by diffusion or other means, (3) the ignition of the gas in the equipment by an electric spark or flash, and (4) the failure of the equipment to prevent the spread of the flame resulting from that ignition.

Flashes from short circuits or grounds from trailing cables of portable machines may readily cause ignition of gas. The trailing cable is, in fact, one of the major hazards in the use of electrical equipment at the face. Ignitions are also possible where short circuits or grounds occur on power and lighting circuits in the presence of gas. The problem of devising adequate safeguards for such circuits has not as yet been given the same special study that has been devoted to the production of motors, controllers, and other electrical appliances. This paper is, in general, restricted to the consideration of safeguards for electrical equipment itself and does not deal with trailing cables or other electrical circuits in the mine.

PRESENCE OF GAS IN ELECTRICAL APPARATUS

Gas is likely to enter the interior of electrical apparatus that has openings large enough to permit diffusion of the gas with the air. Diffusion will take place readily if the apparatus is allowed to remain several hours in a room filled with gas. A machine of the totally inclosed type

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is much less liable to be filled with gas through diffusion than one having gauze or plate attachments designed to relieve pressure or to permit circulation of air. Diffusion, however, is not the only way by which gas enters the interior of equipment. The metallic parts of electrical apparatus are subject to variations of temperature during periods of rest and operation. Consequently, the atmosphere within expands and contracts, creating an unbalanced pressure with the atmosphere outside. This difference of pressure tends to become equalized by the transfer of gases in and out of the casing.6/ Thus, gas may be drawn into the interior of an electric motor or other electric equipment through very small openings. Finally, if covers or other parts are removed while the apparatus is surrounded with gas the exposed interior soon becomes filled with an explosive mixture.

FACTORS BEARING ON SAFETY

The degree of hazard connected with the introduction of a piece of electrical machinery in a gassy mine and the possible results of an explosion within that machine vary with the following factors:

1. Percentage of gas in the atmosphere inside of and surrounding the machine.
2. Amount, condition, and distribution of coal dust (bituminous) in the mine.
3. Degree of turbulence of the gas within the machine.
4. Arrangement and size of spaces that may become filled with explosive atmosphere inside the machine.
5. Protection of sparking parts or parts which may give off sparks by an inclosure so that gas does not easily reach them.
6. Ability of the inclosure to withstand internal explosions of gas and prevent propagation of flame through joints, bearings, or cable entrances.

Spread of Explosions from Open-type Apparatus

If an explosion takes place in open-type equipment, the mixture surrounding it, if explosive, can reasonably be expected to ignite. Such an explosion in an anthracite mine would proceed only as far as the inflammable mixture extended, but in a bituminous-coal mine, owing to the explosibility of coal dust, it might continue throughout the mine. In either event life and property might be lost.

Spread of Explosions from Damaged Apparatus

Good mechanical construction of electrical equipment is necessary. If an explosion takes place in apparatus too weak in mechanical construction, walls will be distorted or destroyed, bolts will be sheared, seams and joints will be opened, and the explosion may spread to the outside with disastrous

6/ Ilsley, L. C., The "Breathing" Action of Electrical Equipment: Bureau of Mines, Rept. of Investigations 2813, 1927, 3 pp.

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results. Some inadequate apparatus is still used in mines because many designers do not fully realize the necessity of providing sufficiently rugged equipment for mine work. Apparatus must be strong enough to withstand pressures of internal explosions so that no path will be made for flames to escape and ignite explosive mixtures outside.

Spread of Explosions Through Openings in Apparatus

Small openings which have been overlooked by the designer, maker, or user are a source of possible hazard in inclosed motors and other electrical accessories. These openings may be around lead wires or at bearings, or they may result from the omission of bolts or cap screws in holes tapped through the inclosure. In permissible equipment precaution is taken to reduce the chance of such openings to a minimum. Lead entrances and paths through bearings are proved flame tight by actual tests in gas, and the possibility of through bolt holes is generally eliminated by requiring that bolt holes be bottomed. In spite of these precautions, careless assembly of parts may render permissible equipment unsafe. An explosion within electric apparatus may also be propagated through specially protected openings that are sometimes used either to provide for a degree of ventilation through the apparatus or to permit the relief of pressure following an internal explosion. Through improper design, neglect, or damage, these openings may fail to cool the escaping flames below the ignition temperature of the gas. Their behavior cannot readily be predicted, and their ability to prevent the discharge of flames can only be determined by tests in explosive gas of the particular equipment to which they belong.

Characteristics of Methane

Ordinarily the only gas that occurs in coal mines in quantities sufficient to cause an explosion is methane, whose chemical formula is CH_4. The characteristics of this gas will be briefly considered, so that the basic principles governing the design and test of suitable inclosures for mine electrical equipment may be better understood.

Inflammability Limits of Methane

Continued propagation of flame in mixtures of air and methane that contain less than 5 percent methane is impossible, whether the mixtures be quiescent or turbulent. When such mixtures contain more than about 15 percent methane, continued propagation of flame again becomes impossible. These "limits of inflammability" are not affected appreciably by the ordinary variations of atmospheric temperature and pressure, but small quantities of methane facilitate the propagation of flame in atmospheres containing considerable coal dust in suspension.

Ignition Temperature of Methane

Methane is ignited in air at about 650° C.1/ To obtain ignition, a sufficient volume of the inflammable mixture must be maintained at or above

1/ Dixon, H. B., and Coward, H. F., The Ignition Temperature of Gases: Trans. Chem. Soc., vol. 95, 1909, p. 514.

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its ignition temperature for a long enough period. Consequently, small electric or friction sparks may fail to ignite methane, just as weak sparks fail to ignite gasoline; even large flames of momentary duration may not ignite methane. In general, however, the temperature of a strong electric spark or flash so far exceeds the ignition temperature that its duration insures an explosion in an explosive mixture; and a flame, except sometimes that of an explosive, usually lasts long enough for ignition of methane.

Explosion Pressures of Mixtures of Gas and Air

The physical-chemical section of the Bureau investigated the effect of the initial pressure upon the pressure developed when explosive mixtures of Pittsburgh natural gas and air are ignited. A mixture containing about 8 percent of natural gas under atmospheric pressure, ignited in a small steel chamber, gave a maximum pressure of 74 pounds per square inch, as measured by a Crosby gas-engine indicator. A second mixture in the same chamber having a similar percentage of gas, under 10 to 12 pounds pressure above atmospheric, gave a maximum pressure of about 135 pounds per square inch.

Although these results are based upon special conditions, with other conditions constant a slight increase in initial pressure evidently has a marked effect upon the violence of the explosion.

If an explosion takes place in a compartment where parts, such as the armature of a motor, are in rotation, the pressure is developed more rapidly because of the turbulence of the mixture and is consequently higher. Sometimes the external gases are drawn into a motor interior immediately after an explosion and continue to burn. This action is usually termed "afterburning" and if prolonged may damage the insulation; but, what is more serious, the heating may allow flames to pass to the outside of the apparatus through protected openings or special "protective devices" that would otherwise be effective in cooling them.

When an explosive mixture composed of methane and air only and uniformly distributed throughout the interior of the apparatus is ignited from a fixed point, reasonably consistent results are obtained so far as flame and explosive pressures are concerned. The pressure at any given point within the apparatus will depend on where the explosion was initiated and to a certain degree on its proximity to relief openings. At different points the pressure is greater or less, according to the distance the flame has traversed before reaching that point and on the arrangement of the internal unoccupied space.

The explosion will be most violent when the explosive mixture in the inclosure contains between 8 and 10 percent methane, but will not necessarily be most liable to result in an exterior explosion,[8] as experiments have

[8] Beyling, C. Versuche zwecks Erprobung der Schlagwettersicherheit besonders geschutzter elektrischer Motoren and Apparate sowie zur Ermittlung geeigneter Schutzverrichtungen fur solche Betriebsmittel: Berggowerkschaftlichen Versuchsstrecke in Gelsenkirchen, 1906, 89 pp.

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demonstrated that a lower percentage of gas will cause flames to pass more easily through holes of gauze-protected pressure-relief openings.

Effect of Internal Arrangement of an Electrical Machine

The arrangement of parts within a machine may have a marked effect upon the pressure developed by an explosion of gas inside. When an explosion begins at one end of a long closed passage, the pressure precedes the flame, and in this way the gas is compressed before being ignited. Consequently, as the flame advances into the compressed gases the explosion pressure increases. This effect is termed "pressure-piling."

Similarly, when two or more compartments are connected the pressure-piling may become exceedingly dangerous, especially if the ignition starts in a large compartment connected by a narrow passage to a small compartment. Isolated compartments or an arrangement of parts that will not result in excessive pressure should therefore be followed in the design of permissible-type equipment.

Effect of Coal Dust in the Apparatus

Coal dust may be present in the gassy mixture as a dust cloud whose density is a variable quantity difficult to measure or duplicate under ordinary testing conditions; or the dust may be in the form of a deposit, various amounts of which may be stirred up by the force of an explosion. Some of these coal particles are distilled, some are decomposed and enter into the combustion, and some are driven out through openings in an incandescent state. Tests made by the Bureau of Mines have not shown definitely that the presence of coal dust within the apparatus increases the danger from explosion. In the numerous tests of apparatus made by the Bureau coal dust appears, in general, to lower the explosion pressure if the most explosive mixture of gas and air is used and to increase the pressure to a less marked extent if lower percentages of gas are used. However, there are so many exceptions that the effect of the coal dust in any particular case can not be predicted. Aside from its effect upon the characteristics of the explosion, coal dust serves a useful purpose in practical testing work by making flames readily visible. Very hot flames of natural gas may have the characteristics of the flame of a Bunsen burner and be virtually invisible in daylight, but the presence of even a small amount of coal dust colors the flame and makes it easily seen.

PROBLEM IN CONSTRUCTION OF PERMISSIBLE-TYPE EQUIPMENT

From the foregoing consideration of the characteristics of methane one will see that the main problem confronting the manufacturers of mine electrical equipment is construction of enclosures so that joints (and relief openings of protective devices, if used) will abstract enough heat from any flames tending to escape to cool them below the ignition temperature of methane, 650° C., and so that the enclosures will be strong enough not to burst when gas is exploded in them. Cooling may result from contact of the flames with metallic surfaces at joints or discharge openings of protective

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devices through which they pass, from sudden expansion of the gases as they are released from the enclosure, or from both contact and expansion. In fact, while one or the other of the above conditions may predominate, some cooling from contact and some from expansion always will take place, as the flames must come in contact with the sides of the openings through which they escape, and there will be expansion as the products of combustion reach the surrounding atmosphere after being forced out under pressure of the internal explosion.

In the foregoing an effort has been made to show something of the need for special construction of electrical equipment so that it may not be a contributing cause of a mine disaster. Certain details followed by several manufacturers in the construction of this special type of equipment have been described in other publications of the Bureau, and therefore the various phases of designing machines will not be discussed here.

The course pursued by the Bureau of Mines in determining the safety of the design of equipment will be considered next. This procedure is outlined briefly in a "schedule," the current edition of which is designated Schedule 2D. This schedule gives the procedure to be followed by the manufacturers in submitting equipment for investigation and prescribes certain inspections and tests designed to disclose any unsafe features. It also gives requirements to be met in the construction of bearings, cable entrances, and other parts that must be made properly to prevent failure in test. In addition, the fees charged for the investigation are itemized.

Preliminaries in Approval for Permissibility

When a manufacturer has built a coal cutter or other electrically operated machine that he desires to have approved as permissible for use in gassy coal mines the first steps to take toward obtaining approval are as follows:

1. A letter should be written to the Director, Bureau of Mines, Washington, D. C., applying for inspection and tests leading to approval of the machine. A copy of this letter should be sent to the Electrical Engineer, Bureau of Mines Experiment Station, 4800 Forbes Street, Pittsburgh, Pa.
2. A certified check or bank draft made payable to the Treasurer of the United States for an amount to cover the charges for inspections and tests should be sent with the original letter to Washington.
3. A complete set of detailed working drawings showing the dimensions, material, and relative arrangement of parts should be sent to the Electrical Engineer, Bureau of Mines Experiment Station, 4800 Forbes Street, Pittsburgh, Pa.
4. The drawings should be accompanied by a description of the equipment, which should include the complete rating of each motor, the capacity of fuses, the capacity and setting of overload relays and circuit-breakers, the method of controlling and protecting each motor, and a diagram of electrical circuits

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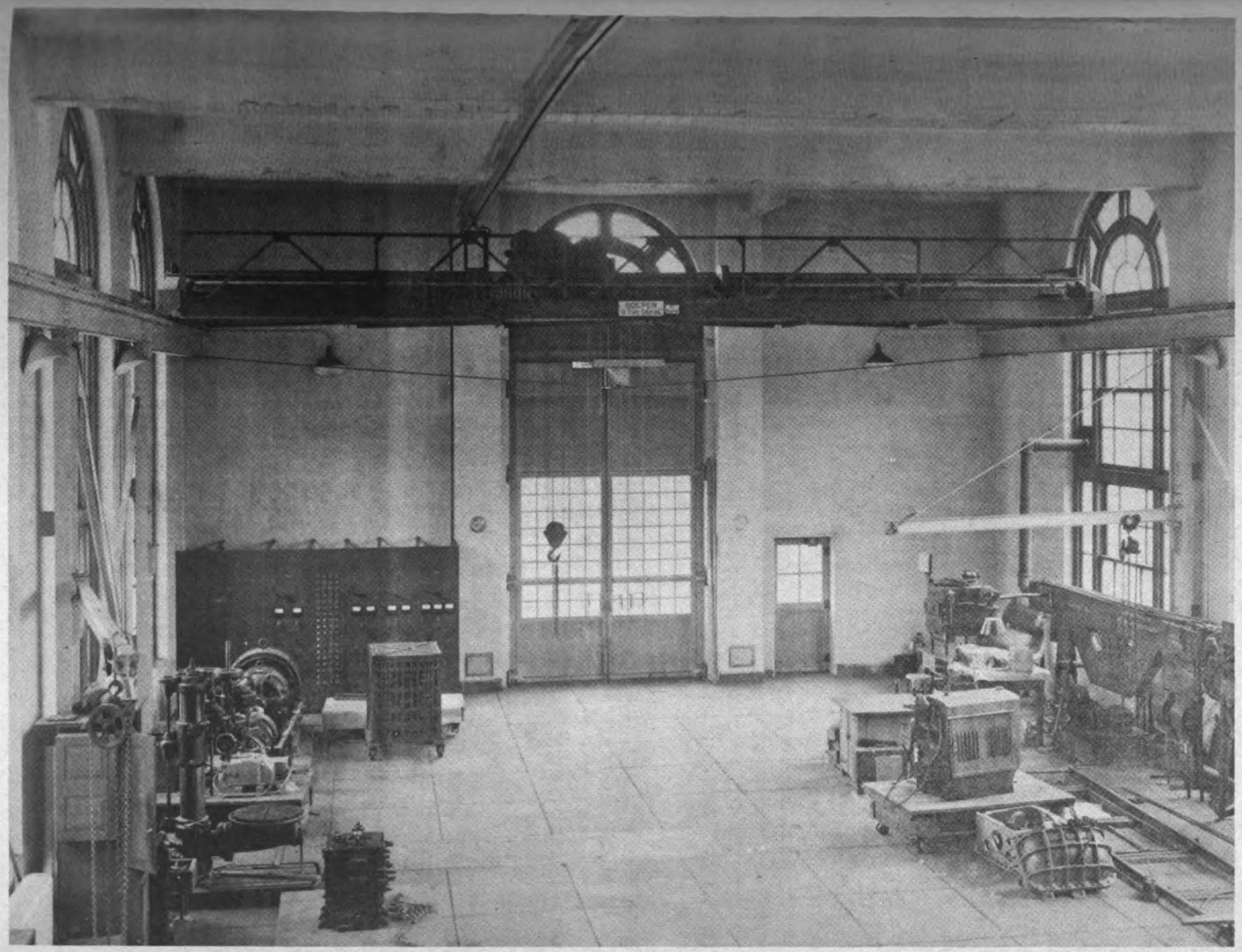

Figure 1.- Main laboratory for inspection and preparation of equipment for tests.

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in the machine. If a trailing cable is used with the machine, its size, make, and type and the provision for attaching it to the power circuit should be specified.

5. Unless notified to the contrary, the manufacturer should send, prepaid, one complete set of electrical accessories for test and inspection to the Bureau's Pittsburgh Experiment Station, marked for the attention of the Electrical Engineer, as soon as convenient after making application. Any special tools, such as bearing pullers, that may be required in taking the machine apart should accompany the equipment. Gearing and other mechanism that do not form part of the electrical enclosures need not be sent; that is, it is generally not necessary to send a complete machine when the motors, controllers, and rheostats can be dismounted from the bedplate or frame.

Criticism of Proposed Designs

Manufacturers inexperienced in designing equipment to meet the Bureau's requirements and sometimes those having experience desire advance information and advice so that features obviously unsuitable may be eliminated before actual construction is started. The Bureau's engineers at Pittsburgh are ready to offer assistance by pointing out in what respects the design is unlikely to pass the specified inspections and tests. This is best accomplished by having the manufacturer's representative, preferably some one from the engineering department, furnish fairly complete drawings for the proposed design to the Bureau's engineers and discuss with them any questionable feature. A number of manufacturers have availed themselves of this opportunity of conferring on questions of design and have thus saved time and effort in developing machines for approval. No charge is made for this assistance.

Inspection of Accessories

The Bureau places great emphasis on thorough inspection of all electrical accessories, such as motors, rheostats, controllers, headlights, etc. The object of the inspection is twofold: (1) To compare the apparatus with the manufacturer's dimensional drawings to ascertain if the design specified is the same as that of the sample accessories tested and inspected by the Bureau, and (2) to become more familiar with the construction and assembly of the parts and discover unsafe conditions that might be overlooked if drawings only were consulted.

To make such an inspection the apparatus must be completely disassembled. This work is done in a large laboratory convenient to the testing gallery. Figure 1 is a general view of this laboratory, which includes facilities for handling motors and other electrical units shipped in for test. These consist of a 3-ton electric hoist, a 5-ton electric traveling crane, and several chain hoists of 1 and 2 tons capacity. Material can be unloaded from trucks and brought into the laboratory through the large doors at the rear by means of the 3-ton hoist, or trucks can be

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backed through these doors for unloading by the 5-ton hoist. Various sizes of platforms mounted on casters facilitate moving the parts during inspection and preparation for tests. Photographs of assembled and disassembled parts constitute an important portion of the Bureau's records, and these platforms are useful for supporting the parts to be photographed.

In connection with such an inspection certain general data are desirable if the equipment is to be completely identified, such as: (1) Name of equipment and date of its receipt. (2) Complete rating of equipment. (3) Is equipment new or revised from parts already tested by the Bureau? (4) If revised, how is it essentially different from equipment originally investigated? (5) Does submitter manufacture essential parts? (6) If not, give name of builder.

The Bureau makes a record of all discrepancies between drawings and apparatus submitted. These differences are called to the submitter's attention so that corrected drawings may be furnished. If drawings prove inadequate to identify the equipment properly, more complete drawings are requested.

The following inspection outline indicates the extent to which the Bureau goes in an endeavor to check those features bearing on the safe operation of apparatus and to have an identifying record of what was actually tested.

Flange Joints

1. Types of flange (plane, step, cylindrical, or irregular). Describe fully.

2. Measure carefully to see if the width and clearances vary from dimensions given in drawings and determine whether the minimum requirements of the schedule are met at all points. (When the internal air space is 60 cubic inches or more in volume, the width of joint must be at least 1 inch, and not less than 3/4 inch for volumes under 60 cubic inches).

3. If the joint does not consist of metal-to-metal contact throughout, note the clearances found.

Covers

1. Describe, including (a) material, (b) shape, (c) strength, and (d) type.

2. Fastenings: (a) If bolted, give number, spacing, and size of bolts, studs, etc., used; (b) describe special designs.

3. Security of fastenings: (a) What is used to prevent cover fastenings from loosening? (b) Does nut bind or screw bottom before cover is clamped by it? (Lock washers, castellated nuts, seal, or equally suitable method must be used to secure bolts, nuts, and other fastenings against loosening).

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4. Covers with glass (for meters and headlights): (a) What material is used for cushioning glass? (Rubber, putty, and plaster of paris are not acceptable for this purpose.) (b) Is glass protected from being struck by falling and moving objects?

5. Locks and seals: Are padlocks or seals used to prevent opening of covers not held by bolts or screws?

6. Design and construction: Are covers satisfactory, and if not, to what extent deficient?

Through Holes

1. List all holes, except bearings, through walls of the casing, including those for field pole bolts and lead entrances.

2. Tabulate holes in which studs, pins, rivets, etc., are riveted or welded in place. Is riveting or welding satisfactorily done?

3. Specifications for holes: (a) Do drawings specify not to drill bottomed or blind holes through? (b) Is welding the end of studs, filling holes with rivets, etc., specified?

4. Special drain or pressure-relief devices: (a) Describe, giving position, purpose, etc. (b) Are they protected against corrosion or clogging with grease and dirt, which might destroy their effectiveness?

Bearings

1. Type of bearing (ball bearing, sleeve bearing, etc.): Give designation by number and maker.

2. Describe path of possible flame through bearing, including (a) whether or not construction agrees with drawings and (b) whether or not clearances are properly specified and if they agree with the specifications.

3. Bearing caps: (a) Does outside cap completely close bearing opening? (b) Is there an oil drain in the cap? (c) How is the cap secured against loosening? (d) Is the cap necessary to retain parts of bearing assembly?

4. Oil holes: Is there a possible flame path through oil holes?

5. Is lubricant necessary to prevent passage of flames?

Lead Entrances

1. Type of lead entrance: Describe fully (stuffing box, insulated stud, etc.).

2. Are stuffing boxes properly packed with enough packing material?

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3. Are parts secured against loosening?

4. Are terminals adequately secured to prevent loose contacts?

5. Are satisfactory strain clamps provided for holding cables?

6. Are outside terminals adquately protected against accidental contacts, short circuits, and mechanical injury?

7. Is the wiring inside of compartments adequate and is it properly supported and protected?

8. Are cables adequately specified as to type, size, number of conductors, etc.? Special note should be taken of leads for resistor compartments and those passing through stuffing boxes.

9. Are splices outside of compartments indicated and are they insulated satisfactorily?

Conduits

1. What type of conduit is used (hose, metal, etc.)?

2. How is conduit secured: (a) To the compartments, (b) between compartments?

3. Are arrangement and fastening of conduit satisfactory?

Electrical Clearances and Insulation

Are parts of opposite polarity adequately insulated or separated from each other and from the metal walls of the enclosure? (If the amount of clearance does not appear satisfactory, electrical tests should be made to prove whether or not the clearances are adequate.)

General

1. Inspect for workmanship, general design, and adequacy of materials used.

2. Special items: (a) Note rated capacity of fuses (or setting of overload relays). (b) Does ease of renewing fuses or resetting of circuit breakers comply with schedule requirements; are adequate interlocks used, etc.? (c) Are there any partitions or barriers in the compartments that might cause pressure piling?

Drawings

Most electrical machines are composed of several complicated parts. To identify all of these parts completely usually requires a large number of general and detailed drawings. These are stamped with the date of receipt and are kept on file by the Bureau.

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Drawings constitute the chief record of the designs approved by the Bureau and are the basis upon which approval is granted. For this reason a painstaking comparison of the drawings and the material inspected is made. The material must conform to the drawings, and all machines built under a given approval number must adhere strictly to the record drawings. For example, if a cast-steel controller enclosure is submitted to the Bureau for inspection and tests the drawings must specify that material. A change to cast iron in the course of regular manufacture without inspection or test by the Bureau might result in a burst casting if an explosive atmosphere should reach the interior of the controllers. This does not mean that changes are prohibited after approval has been granted. If a modification is wanted to improve the machine or correct some undesirable feature the submitter should apply for an extension of approval, explaining the changes desired and submitting revised drawings. If the change does not affect the strength of materials, internal volume, or flame paths, an extension of approval is generally granted without inspection or test.

EXAMINING AND TESTING EQUIPMENT FOR PERMISSIBILITY

The most satisfactory method of proving a computed factor of safety is to subject the theoretical to a practical demonstration. Likewise, the most satisfactory proof of the safety of an explosion-proof electrical accessory is to subject it to the adverse stresses and strains that occur when an explosive mixture that fills the compartment is ignited. The Bureau's wide experience in testing explosion-proof electrical accessories of numerous designs and makes has frequently demonstrated that even manufacturers experienced in the design of permissible-type equipment occasionally submit unsafe and weak designs. Within 1 year three important firms submitted compartments that failed when subjected to explosion tests. Actual test is needed to assure adequate design.

The weakness of a compartment is not always evident from an inspection, although an experienced investigator often can foresee it. However, the facts concerning the suspected weakness can be readily determined by a few tests in an explosive mixture. If the compartment fails there can be no argument concerning its proved weakness, and a new and stronger design will be necessary. Tests in explosive mixtures are also of value in that they frequently reveal unforeseen deficiencies.

Facilities for Testing

Owing to the size and weight of the equipment investigated, large apparatus is needed for effective testing. In this respect, the Bureau's appliances for permissible testing of equipment in explosive atmospheres is believed to be the most complete of that of any country and is the only one of its magnitude in the United States.

The laboratory in which the assembling and inspection of equipment takes place has already been shown in figure 1. It includes a large radial drill press for drilling the compartments when preparing them for tests in explosive mixtures. The several cranes already mentioned in connection with

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the inspection work are also available for handling the equipment when preparing it for test.

An overhead craneway extends from the inside laboratory to the testing gallery outside (fig. 2). This craneway facilitates handling of equipment between the laboratory and the testing gallery and thereby greatly expedites routine testing.

The testing gallery (fig. 3) was donated to the Bureau early in its investigative work by several manufacturers of mine equipment and has proved very effective. The work that can be performed with it in a day is at least four times that accomplished with the former less-developed type of testing gallery.

One of the serious problems in large-scale tests of electrical equipment for permissibility is to provide enough gas suitable for producing the explosive mixtures. The Bureau is particularly fortunate in having available an ample supply of natural gas taken from the Pittsburgh supply mains. This gas is not only especially convenient and comparatively inexpensive, but it also has a composition and characteristics that make it particularly suitable for such investigations. Although the composition varies from time to time, a typical analysis is 82 percent methane, 16.4 percent ethane, 1.5 percent nitrogen, and a trace of carbon dioxide. The methane content usually exceeds 80 percent. The suitability of natural gas for testing purposes was the subject of a special investigation conducted in the Bureau's gas laboratories to determine to what extent the use of natural gas in place of methane is justified. The following conclusions were reached as a result of this investigation:

> These general conclusions show that natural gas is somewhat more inflammable than methane. The use of natural gas instead of methane for testing electrical equipment, flame safety lamps, and explosives for their safe use underground is therefore justified so far, for any difference between natural gas and methane is on the safe side; moreover, the differences are not so great that any hardship is imposed on the makers of such equipment by the slightly greater stringency of the tests with natural gas.

Where the term "gas" is used in describing the Bureau's tests, Pittsburgh natural gas is meant.

Details of Apparatus

The complete testing gallery consists of the following parts: (1) An explosion chamber in which the mine equipment is tested; (2) a fan and piping system for mixing and circulating the explosive mixture in the explosion chamber and in the equipment under test; (3) a switchboard on which are mounted the electrical controlling apparatus and wiring for directing the action of the gallery; (4) a crane (previously mentioned) surmounting the gallery and equipped with a 3-ton electric hoist; (5) other miscellaneous apparatus, including a gas meter for measuring the gas admitted to the

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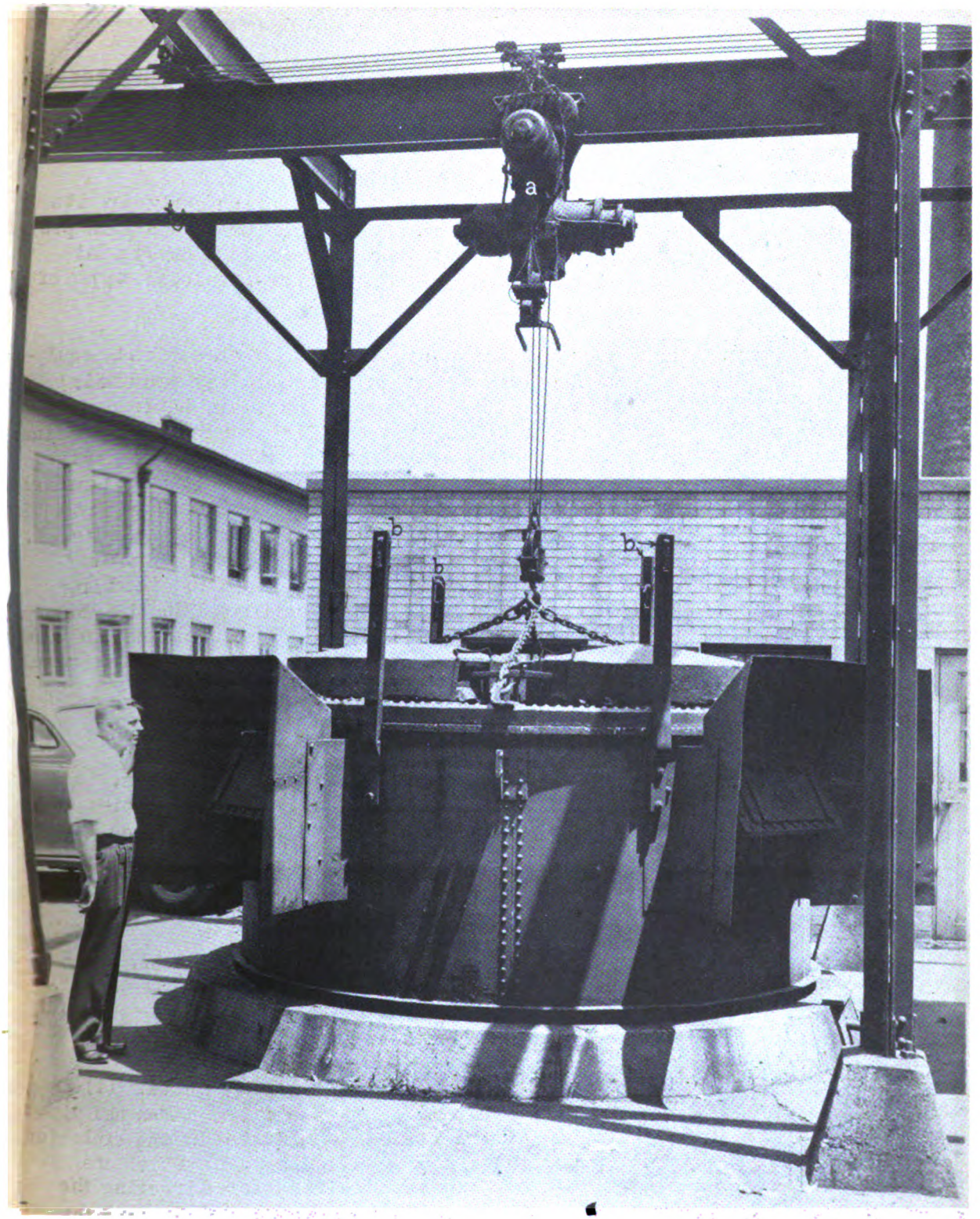

Figure 2.- View of test chamber with 3-ton crane.

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Figure 3.- View of test chamber ready for a test.

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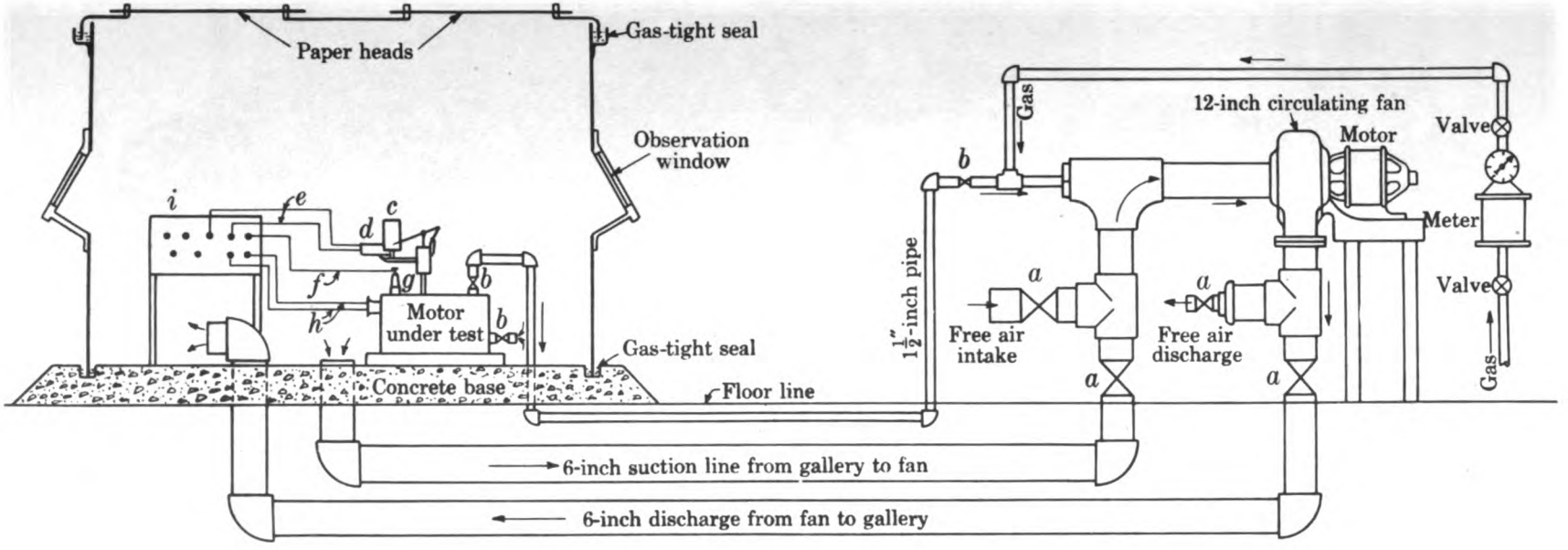

Figure 4. -- Diagram of gallery; a, Control valves, gallery circulating system; b, control valves, motor circulating system; c, recording pressure indicator; d, release magnet for pressure indicator; e, connection from switchboard to release magnet; f, ignition line; g, spark plug; h, power lines to motor; i, terminal board.

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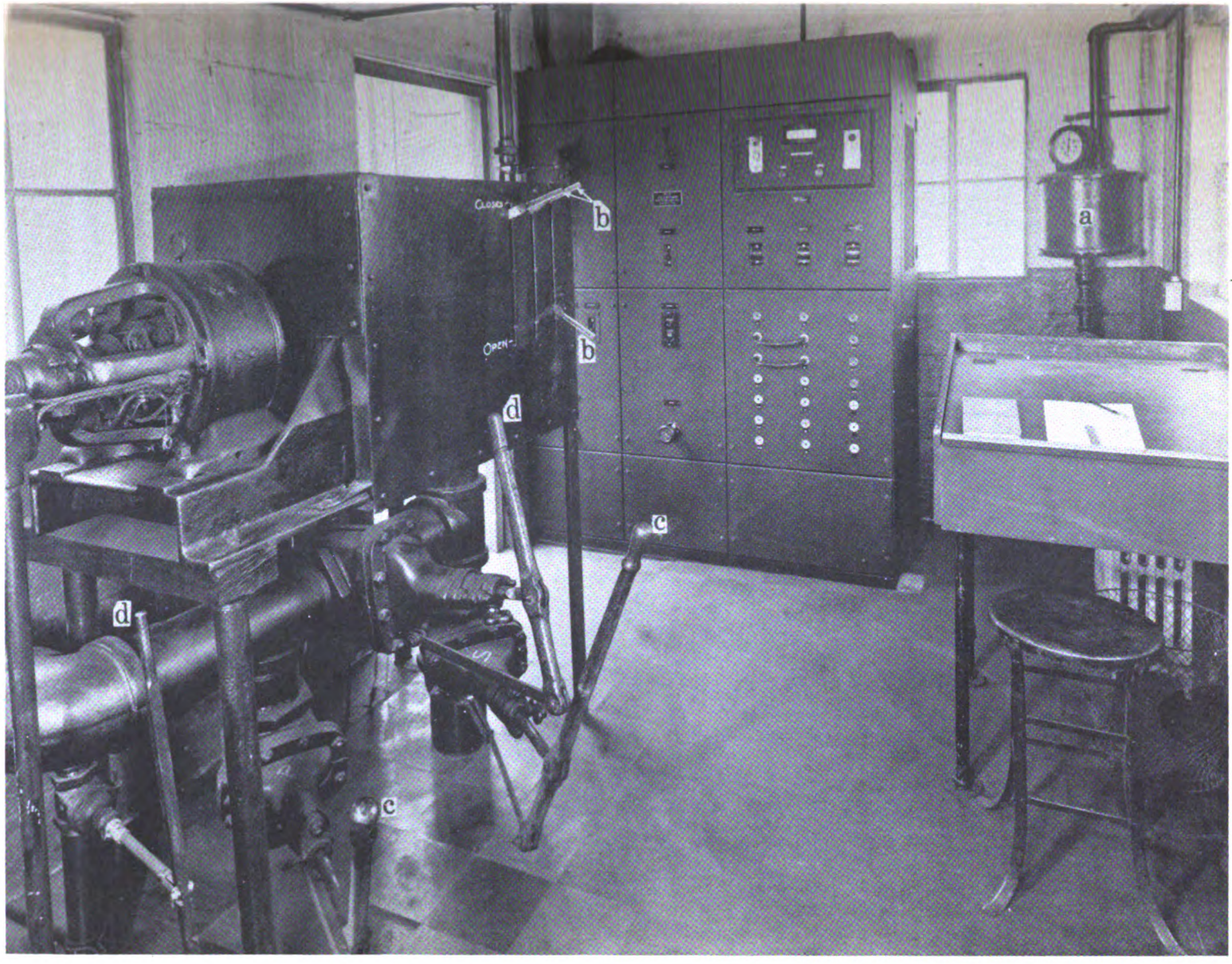

Figure 5.- Switchboard and valves for controlling tests.

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gallery, a recording pressure indicator that can be attached to the casing of the equipment under test for recording the pressure developed therein by the explosion, and spark plugs that can be mounted at desired points in the equipment to initiate the explosions within the casing. Figure 2 shows the gallery proper.

The explosion chamber consists of a cylindrical steel shell with a circular top or cover. The shell has an internal diameter of 10 feet and a height of 4-1/2 feet. The lower edge of this shell is sealed with pitch in a channel made in the concrete base. Figure 3 shows the gallery closed in readiness for a test. Two testing engineers are in position at observation windows for noting the results. The engineer at the left has his right hand on the firing switch for closing a circuit that causes a spark to ignite the explosive mixture within the motor or other part under investigation. The small building at the left houses the apparatus for circulating the explosive mixture in the chamber as well as necessary control for the hoist and other electrical circuits.

The cover of the chamber can be raised for clearing out the explosive mixtures and for entrance of testing engineers to make necessary changes in connections, replace pressure indicator cards, and examine the equipment under test. The cover is slightly more than 10 feet in diameter and has a downward-projecting rim that rests on a rubber seal in the channel around the top of the chamber.

For quick release of pressure when the mixture in the chamber explodes, the cover is provided with four openings covered with waxed-paper heads or diaphragms. These paper heads, which are 42 inches in diameter, are each clamped in position by a cast-iron ring having a rounded edge that fits closely in a turned groove around each opening. The diaphragms are made of black paper to exclude light from above. When the gallery is not in use, they are protected from the weather by sheet-iron covers.

Four windows with glass 1 inch thick are equally spaced around the chamber and permit testing engineers and witnesses to observe the results of each test. Observations are made through slots in wooden covers over the windows, the slots not in use being closed to exclude outside light. Sparks and flames issuing from joints, bearings, or other openings of the part under test can be seen more readily if the interior of the chamber is darkened. The windows are partly shielded with sheet-metal hoods to protect the observers from flames from the top of the chamber when there is an explosion inside.

Figure 4 is a diagram of the testing apparatus in elevation and shows clearly the arrangement of fan, valves, and piping used in making and circulating the explosive mixtures.

Figure 5 shows the switchboard for controlling the various electrical circuits and apparatus necessary in the operation of the gallery. Beginning at the left, the first panel includes controls for the 3-ton crane, switches for lighting circuits, and a rheostat for use in starting direct-current

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motors under test. The center panel includes a switch with speed control for the circulating fan. The third panel includes a thermal-conductivity instrument at the top for checking the gas content of mixtures in the test chamber, and three circuit-breakers protecting the test circuits that extend into the explosion chamber. Below these circuit-breakers is a plug-and-socket arrangement that gives flexibility in the selection and control of the gallery test circuits. Meter a measures the cubic feet of gas required in making the explosive mixtures. Levers b are used to operate valves in the piping connections of the apparatus under test. The filling of this apparatus with explosive mixtures and the subsequent isolation of its contents from the piping and from the surrounding mixtures are effected from outside the testing chamber.

Levers c and d control valves in the circulating system between the fan and testing chamber. To protect the fan against destruction by an explosion traveling into the circulating system from this chamber, the valves controlled by levers c are closed before each test, and the explosive mixture in the fan is displaced with fresh air by opening the valves controlled by levers d.

Figure 2 shows the gallery superstructure and the crane used with the testing gallery. Crane a raises and lowers the cover and transfers apparatus between the main laboratory and the gallery. It is also employed for loading and unloading of shipments of test apparatus.

Two tests are generally made with each mixture of explosive gas prepared in the testing chamber. The cover is then raised and held by safety catches in uprights b while the chamber is being cleared of gas and while engineers are inside. As the entire top of the chamber can be lifted, the gas is removed quickly with the fan and there is little delay between tests.

Test Procedure

Preparing Equipment for Explosion Tests

As previously stated, equipment is prepared for test in the main laboratory (fig. 1). The preparations are not complicated and consist mainly of drilling and tapping two sets of holes in the part to be tested. One set of these holes serves as pipe connections to admit gas to the interior. When feasible these holes are drilled and tapped for 1 1/2-inch standard pipe; otherwise smaller holes are made. These gassing holes, usually two in number, are placed so as to obtain the longest path between the point of entrance and the point of exit for gas circulated through the compartment. If the internal arrangement is complicated, additional gassing holes sometimes are necessary to insure having the compartment completely filled with the explosive atmosphere. The second set of holes is used for two purposes: (1) For attaching a recording pressure indicator and (2) for inserting spark plugs. These holes are drilled and tapped with 1/2-inch standard right-hand pipe thread and are used for both spark plugs and the pressure gage. They are placed with a view to learning the point of highest pressure developed for various points of ignition.

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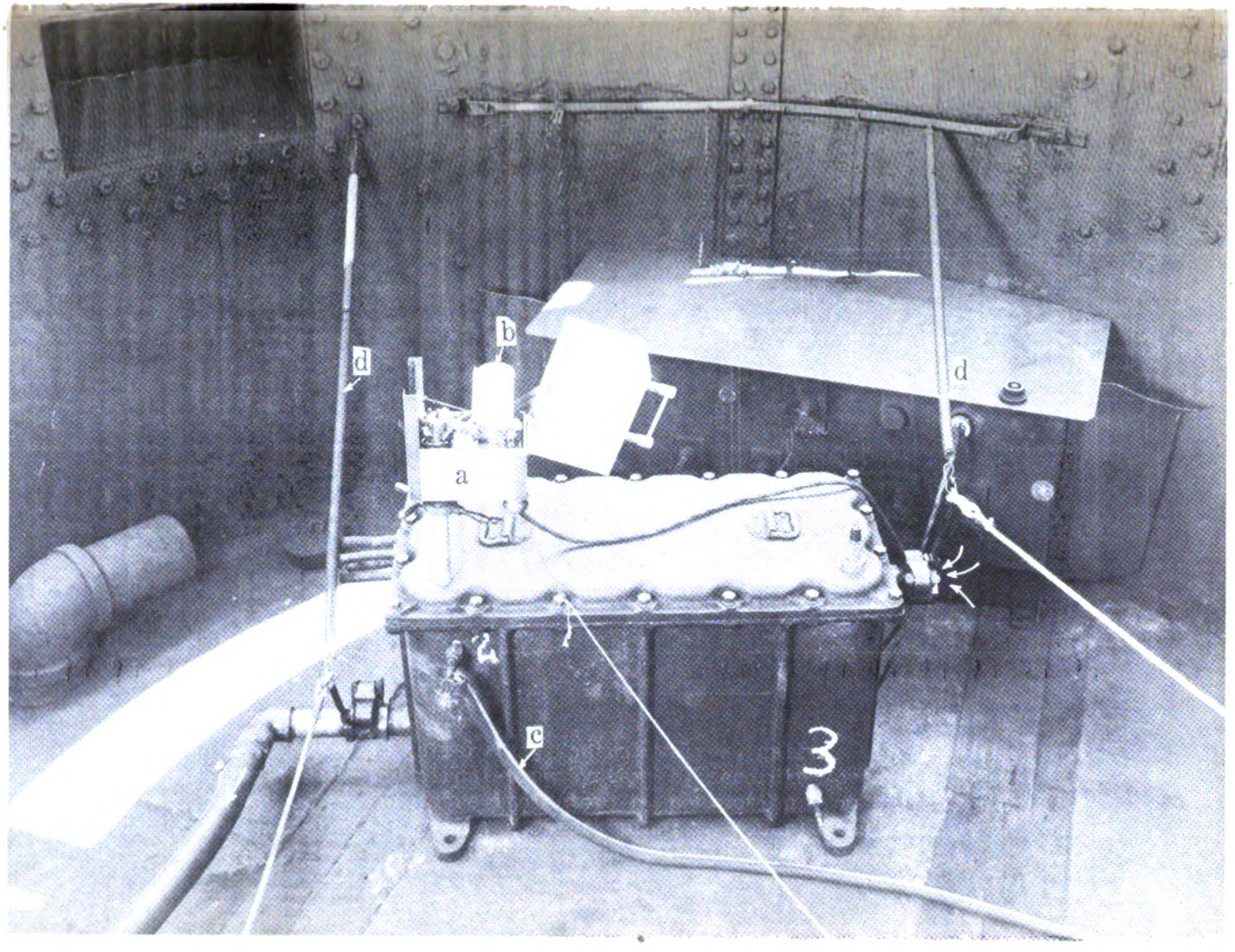

Figure 6.- Rheostat box arranged for test in gallery.

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Sometimes the Bureau's engineers can indicate on a blue print the position of the holes required for the explosion tests, so that the holes can be drilled and tapped at the factory before the material is shipped to the Bureau's testing gallery. When the holes cannot be satisfactorily spotted from a study of the blue prints, they must be prepared after the equipment arrives at Pittsburgh.

The manufacturer is required to provide a man to assist in preparing equipment for test. The Bureau's laboratory is equipped with a drill press and the necessary tools for this work. The company is notified by the Bureau when this assistance is required, that is, the date on which work on their equipment is to commence. It is to the manufacturer's advantage to send some one not only familiar with the equipment but also familiar with company procedure in handling changes in design and corrections in specifications, so that besides being able to assist in assembling, disassembling, and preparing the equipment for tests he can materially expedite the handling of these matters. In many cases this same man can conveniently serve as the company's official witness of the tests.

After drilling and tapping and after again assembling the equipment, the next step in preparing for tests is to mount the parts in the testing chamber or gallery so that they can be readily seen through the observation windows. Valves and piping are then attached for circulating the gas-air mixture through the equipment. The recording pressure indicator is then connected at one of the 1/2-inch holes, and spark plugs are inserted in the remaining 1/2-inch holes. If the compartment is a motor, electrical connections are also made so that it may be run. Figure 6 shows a typical set-up in which a rheostat box has been prepared for test. Pressure indicator a is shown connected at point 1 of the several 1/2-inch holes, which are numbered in chalk for convenience in reference during the tests. The indicator-protecting case is open to show chart b, on which pressure is recorded. Ignition cable c is connected to a spark plug at point 2. The other 1/2-inch holes are closed with spark plugs. At the left end of the rheostat box a 1-1/2-inch, quick-closing valve is connected at the point where suction is applied to draw the explosive atmosphere into the rheostat box. The explosive atmosphere enters the box through the 1-1/2-inch, quick-closing valve at the right end. These valves are opened by means of ropes attached to the valve handles. When the ropes are released springs d, fastened to the handles close the valves.

Cycle of Tests

The cycle of tests is as follows:

1. The equipment is placed in the testing gallery and is piped to the gas-circulating system so that any or all compartments can be filled with a mixture of gas and air under atmospheric pressure.
2. Spark plugs are installed at different points, so that the point of ignition will be under the operator's control.

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3. A pressure indicator is connected at different points to record the pressure developed by the explosion in the compartment under test.
4. In tests to determine the effect of the presence of coal dust in the atmosphere the dust is usually forced through the 1/2-inch holes by a hand bellows into the inside of the compartments.
5. When the spark plugs and pressure indicator have been connected at the desired points the testing gallery is closed, and an explosive mixture of gas and air is made by adding the proper quantity of gas and thoroughly mixing it with the air under atmospheric pressure. The number of cubic feet of gas admitted to the gallery to produce explosive mixtures is known from calibration. The proportion of gas generally used in the tests is 8.6 and 7 percent, both with and without coal dust.
6. The explosive mixture is then drawn into the compartment or compartments under test, and the compartment is isolated from the piping and testing chamber by closing the quick-closing gate valves.
7. Observers are stationed at the observation windows of the gallery.
8. The mixture within the compartment is ignited by means of one of the spark plugs. (This ignition is automatically timed with the release of the indicator drum to give a satisfactory pressure diagram.)
9. Observations are recorded.
10. A second test is generally made with the same gas mixture and under the same conditions, the indicator drum being reset from outside the gallery.
11. The gallery is opened and the gas mixture removed by the circulating system.
12. The operator enters the gallery, makes his inspection, removes the indicator card, puts in a new one, and prepares the equipment for the next test.

If the equipment is to meet the test requirements satisfactorily, the gas mixture surrounding the equipment must not ignite, flames must not be discharged from any point, there must be no prolonged afterburning, and excessive pressure must not develop in any of the compartments. The schedule requires that at least 10 tests be made. Usually they exceed 20 in number.

Adequacy of Equipment

Schedule 2D states that the "casings forming the enclosure for class 1 parts shall be of suitable material and especially durable ***." Having this authority, the testing engineer is justified in condemning any evident weakness in construction, although it may not show up detrimentally in the explosion tests. Thus, parts that are unquestionably weak are often condemned as a result of the inspection.

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The Bureau sometimes has resorted to more or less arbitrary tests to gain information as to the adequacy of different accessories. For example, the mechanical durability of batteries used on storage-battery locomotives was open to question. The various makes of batteries were therefore subjected to mechanical abuses, in which, by means of a cam arrangement, they were bumped 100,000 times. The headlights of locomotives were also subjected to similar mechanical abuse and the batteries of the locomotives investigated to settle the question of gassing during discharge. Such tests are valuable where data and experience are lacking.

During recent years the Bureau has been paying particular attention to the adequacy of fuses, circuit breakers, and other protective devices. These are intended to protect the machine and its wiring, and if they do not perform their functions properly the equipment is endangered and made less safe. It is therefore desirable, wherever possible, to test such devices for the maximum load they will meet in service and under conditions as near those met in service as laboratory test conditions permit. Such devices are investigated to see that they will operate without short-circuiting or grounding. Mine equipment is probably more susceptible to these faults than any other class of machinery, owing to crowding of parts in the effort to make the equipment as small and compact as possible. Hence, electrical tests are of value in disclosing inadequacies of insulation or clearance. If inadequate insulation is used or live parts are too close to casings, short circuits or grounds may result and burn holes through the casings. Fuses and other automatic circuit-interrupting devices should be of such a capacity and rating as to protect wiring outside of compartments.

Switches also have been given more attention as permissible testing progressed. A switch should be capable of opening the maximum current permitted by the automatic protection device without short-circuiting or grounding. Some designs have been changed in recent years to meet these requirements, and the result has been more durable switches that are more suitable for the severe conditions prevailing in mines.

COMPLETION OF INVESTIGATION

When the routine inspection and tests have been completed, several things must be done to complete the investigation. If there has been any change in the construction of the equipment that renders any of the drawings obsolete, the testing engineer must obtain corrected drawings from the manufacturer. If the drawings do not identify the equipment completely, additional drawings must be obtained. As soon as a complete set is available a drawing list is prepared that segregates the drawings according to the accessory to which they apply. This list gives the name of the drawing and the date of its receipt and forms the necessary record for reference.

After the equipment has been tested it is usually subjected to a final inspection. Whenever possible it is desirable to inspect a completely assembled unit, including all electric wiring between the various compartments. Occasionally the Bureau's engineers make a final inspection of the

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completed machine after it has been shipped to the mine, but this inspection is usually made at the factory where facilities permit a thorough, convenient, and quick inspection. Also, if any changes are found necessary they can be made most satisfactorily before the machine leaves the factory. Photographs of the completely assembled unit are especially valuable in interpreting the drawings, and the manufacturer is asked to supply the Bureau with copies if possible.

When the investigation has been completed, the wording for an appropriate plate is chosen. A full-size illustration is prepared of an official approval plate that carries a serial approval number to aid in identifying the machine in the Bureau's records.

Finally, the testing engineers make a recommendation to the Director of the Bureau of Mines through the tentative approval letter that official approval be granted. The formal letter ultimately sent to the manufacturer states the conditions under which approval is granted and includes a list of drawings and specifications covering the design approved. With this letter the manufacturer also receives a photographic copy of the official approval plate design. He then has the actual plate made using this copy as a basis. The approved machine to which a plate has been attached may then be termed "permissible."

POSTAPPROVAL INVESTIGATIONS

The designs approved are usually placed in active service soon after approval has been granted. As a result of actual operation it is common experience that some of the accessories considered in the approval may need modification to meet the user's wishes or for other reasons. The modification may be only a minor change or it may represent extensive alterations in one or more of the compartments. In any case the company holding the approval should submit blue prints showing the desired change and request an extension of approval for the changed design. The approval covers only the equipment as originally tested and recorded, and the substitution of new unapproved parts renders the approval of the equipment void.

If the change as shown by the blue prints is a minor one, the Bureau can handle the matter expeditiously. If the blue prints show that the proposed change affects any of the factors upon which the original approval was based, such as internal volume of the compartment, bolt spacing, width of flange, or strength of material, the Bureau probably will ask that the redesigned compartment be forwarded for retest. The Bureau usually does not judge the safety of compartments where the foregoing variables are involved without the aid of information afforded by official tests. If the changed design satisfactorily meets the explosion-test requirement and if adequate drawings and specifications have been furnished, the Bureau can grant extension of an approval without undue delay. If the compartment fails, it is then necessary to submit new designs until a satisfactory one is available.

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The members of the Bureau's electrical staff devote more than half of their time to the consideration of changes in designs already approved. As many as 250 changes have been authorized for certain permissible outfits.

These changes are a necessary part of progress and are so recognized, but close checking is essential because in the maze of changes, some vital safety feature may be overlooked.

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